Temperature Response and Ion Deposition in the 1 mm Tungsten Armor Layer for the 10.5 m HAPL Target Chamber

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Summary of results since last HAPL meeting

- BUCKY simulation for a xenon gas pressure of 8 μtorr was run, using the threat spectra from the “Perkins” empty foam target and was compared to the 8 mtorr xenon case.

- The tungsten armor temperature profile and ion deposition depths for each ion species was computed using the new BUCKY integrated chamber-wall model and ion transport model.

- Ion deposition results were compared to SRIM simulations to validate the BUCKY ion stopping model.

- Preliminary results obtained for most recent coated target threat spectra.

- Work continues on a BUCKY kinetic/hydro model.

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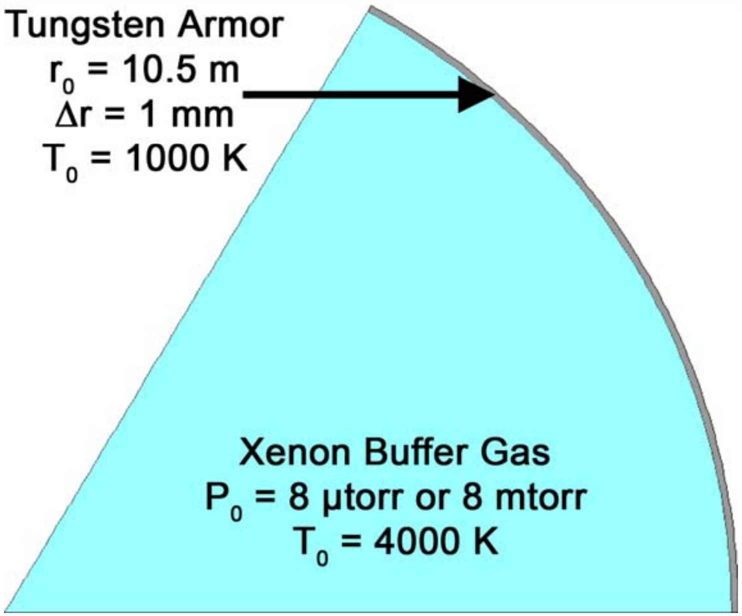
BUCKY radiation hydrodynamics simulation parameters

- Perkins x-ray and ion spectra were used as inputs into a chamber consisting of a xenon gas and tungsten armor
- The initial gas temperature was 4000 K and the initial armor temperature was 1000 K
- Two Xe gas pressures were simulated, 8 mtorr and 8 μtorr
- SESAME EOS data were used for tungsten and xenon
- YAC LTE opacities were used for tungsten and non-LTE opacities for xenon



The BUCKY simulation was performed using the empty foam target ion spectra developed by LLNL

- Perkins fast and slow ion spectra for the 340 MJ empty foam target were used.
- The ion spectra are the results of a LASNEX target simulation at t = 100 ns.
- Ion species modeled in BUCKY: ^{1}H, ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{12}C
- All of the ions in the BUCKY simulation were launched at t = 0 s

Ion Species	LLNL Ion Tally	BUCKY Ion Tally
^{1}H	1.047E+20	1.0466E+20
^{2}H	6.967E+20	6.9669E+20
^{3}H	7.036E+20	7.0363E+20
^{3}He	2.425E+19	2.4247E+19
^{4}He	7.767E+19	7.7668E+19
C	1.023E+20	1.0233E+20

Ion Species	LLNL Slow Ions [MJ]	LLNL Fast Ions [MJ]	BUCKY Slow Ions [MJ]	BUCKY Fast Ions [MJ]
^{1}H	8.114E-01	7.382E+00	8.1230E-01	7.3819E+00
^{2}H	1.221E+01	7.382E+00	1.2213E+01	7.3819E+00
^{3}H	1.717E+01	7.166E+00	1.7167E+01	7.1655E+00
^{3}He	2.252E-02	7.382E+00	2.2523E-02	7.3819E+00
^{4}He	1.519E+00	7.382E+00	1.5187E+00	7.3819E+00
C	8.211E+00	5.493E+00	8.2112E+00	5.2277E+00
Total 1	3.994E+01	4.192E+01	3.9945E+01	4.1921E+01
Total 2	8.186E+01		8.1866E+01	

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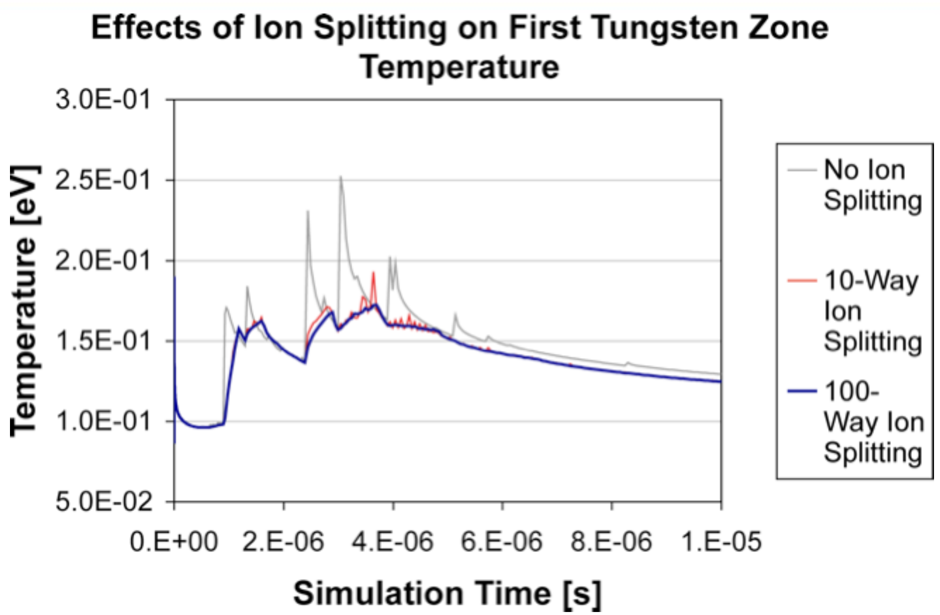
The BUCKY ion splitting model was incorporated to reduce non-physical temperature spikes

- Impinging ions were split once they passed a boundary at 7.5 mm from the tungsten wall.
- The ions were split into 500 evenly spaced bunches to provide a more continuous impingement on the tungsten.
- Ions were overlapped by 25% with the next ion bunch to eliminate "spikes" from time-of-flight ion spreading.
- Implementing these features yields a relatively smooth temperature profile.



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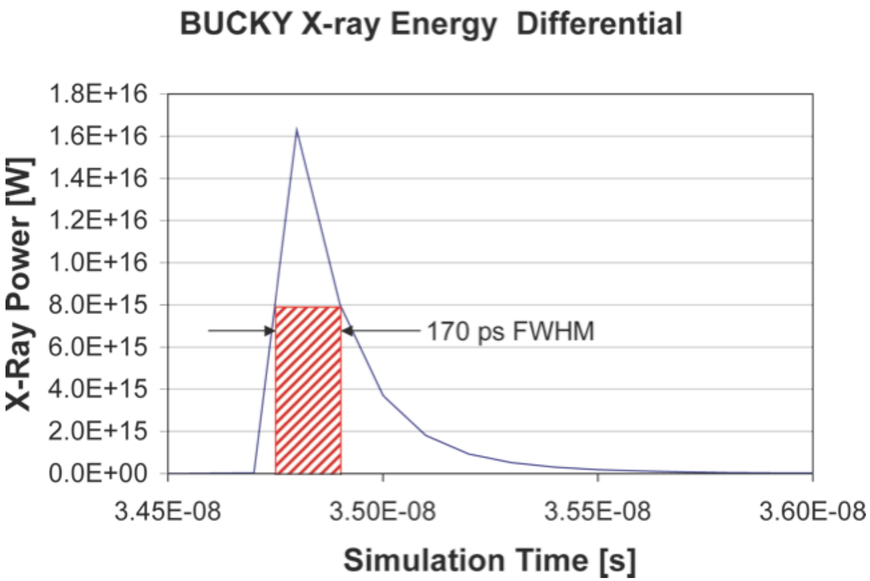
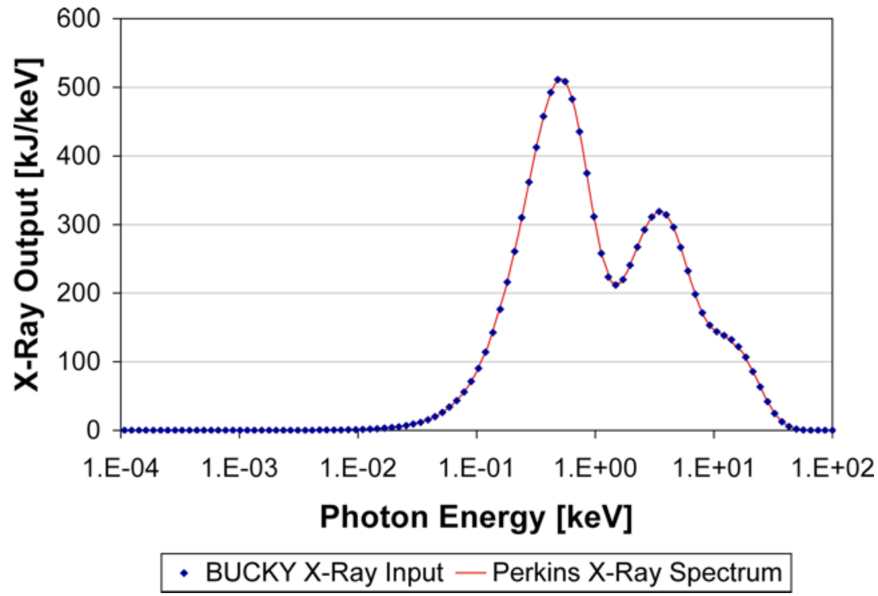
The x-ray spectrum used in the BUCKY simulation was based on Perkins' 3-temperature blackbody curve and a simulated BUCKY target x-ray pulse





- Perkins 3-temperature blackbody x-ray spectrum was used to generate BUCKY x-ray profile.
- 170 ps FWHM Gaussian pulse was used to simulate the time dependence of the fusion burn x-rays.
- The simulated x-ray pulse begins at t = 0.000 ns and ends at t = 0.765 ns.
- The x-ray pulse was divided into 100 energy group histogram with 19 time bins

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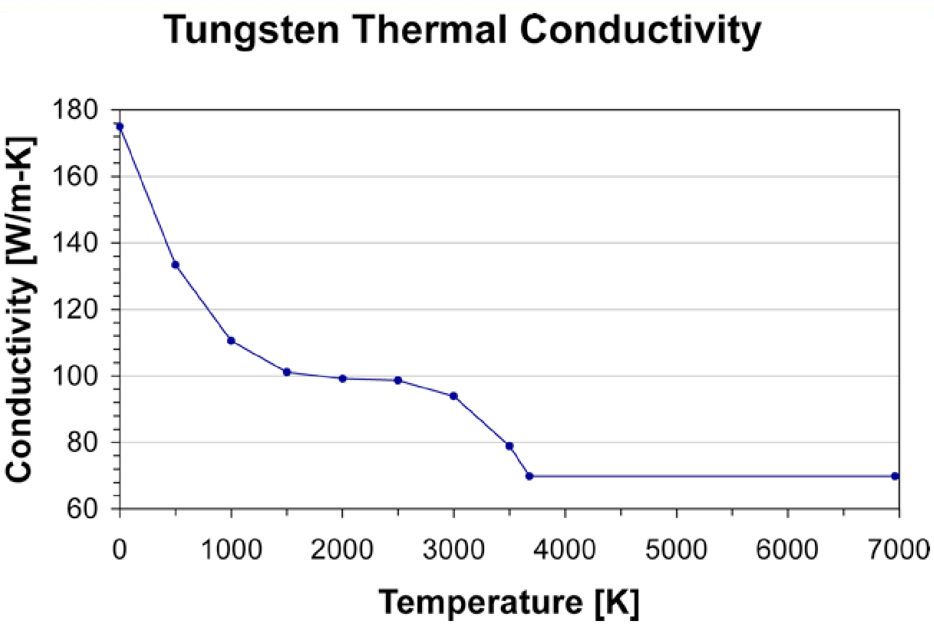
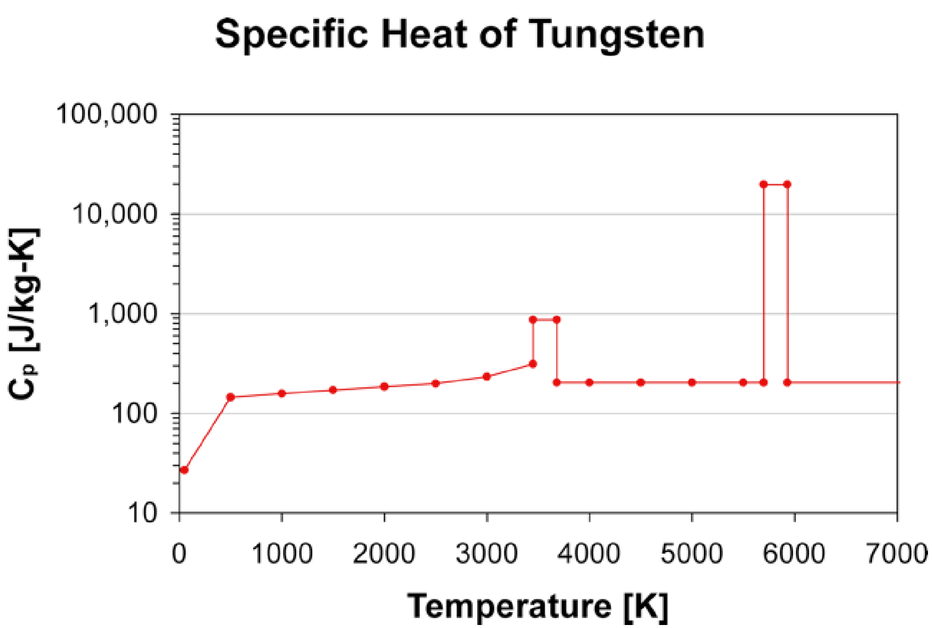
The thermodynamic properties of tungsten were simulated using standardized data sets





- NIST values were used for T_{melt} and T_{boil}, 3680 K and 5930 K, respectively.
- ITER Materials Handbook data was used for thermal conductivity, k(T).
- NIST Shomate Equation was used for heat capacity, $C_p(T)$.

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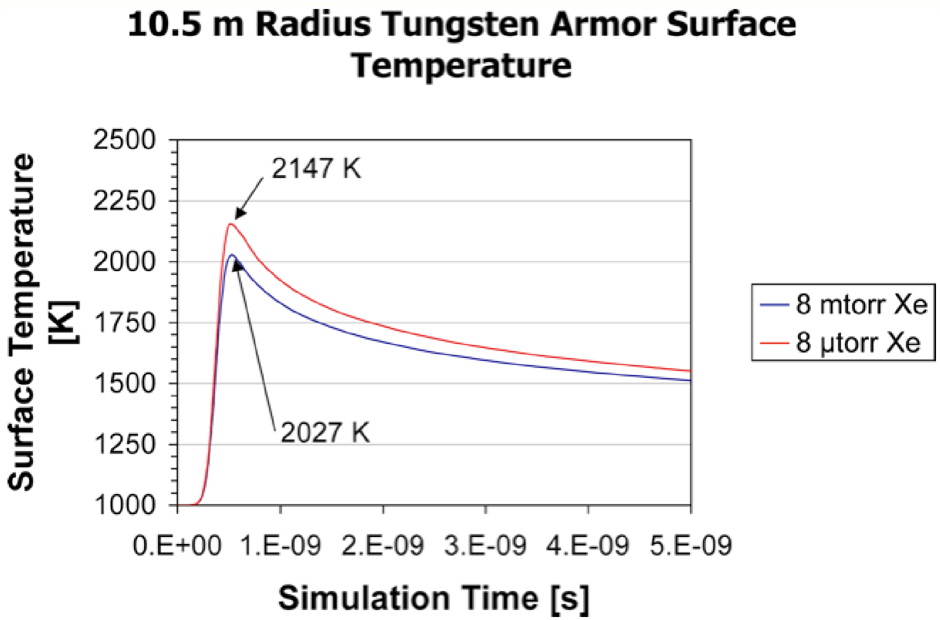
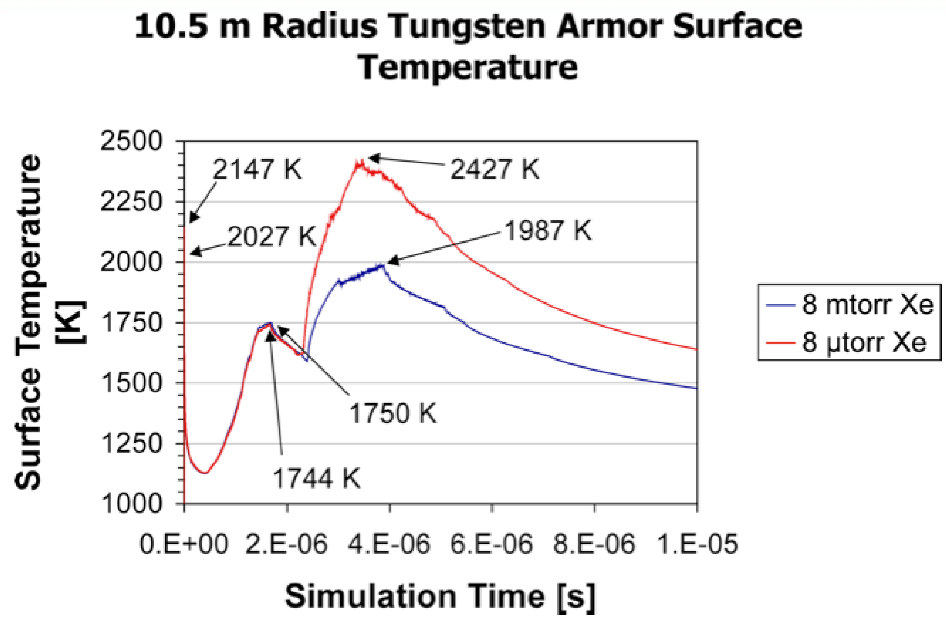
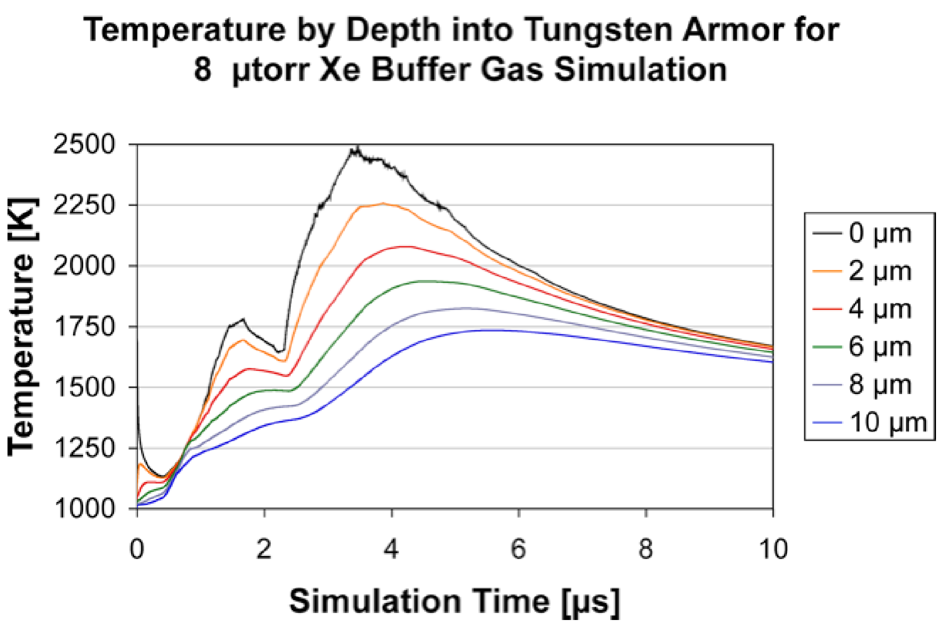
The results of the simulation show 3 temperature peaks: an x-ray peak, fast ion peak and slow ion peak







- Magnetic intervention can reduce the ion peaks, but not the x-ray peak.

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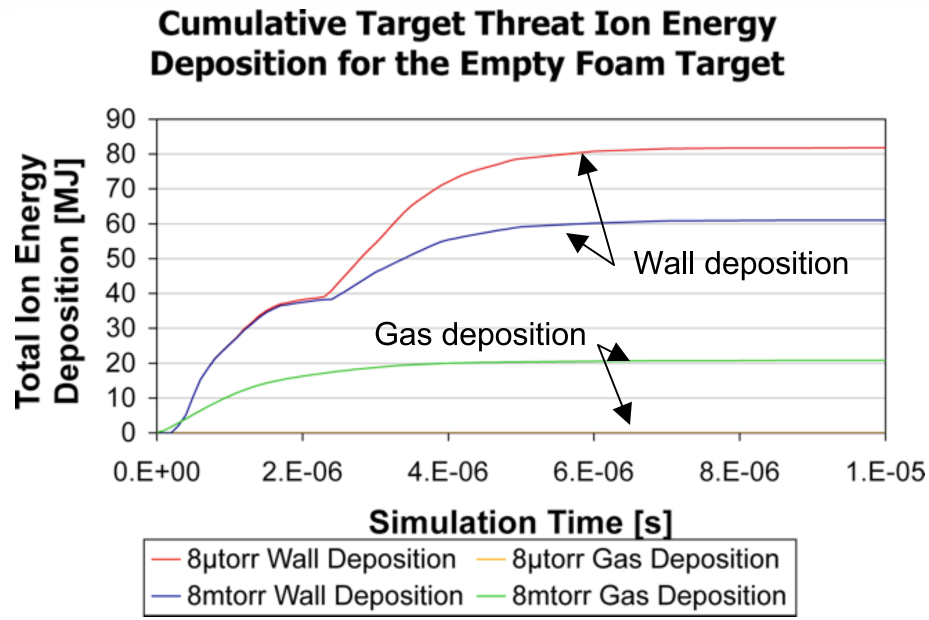
The results of the simulation reveal the ion energy deposition characteristics and stopping power of the xenon gas

Incident Ion Species	8Źmtorr Xe Buffer Gas		8Źµtorr Xe Buffer Gas	
	Number of Ions Thermalized	Percentage of Incident Ions	Number of Ions Thermalized	Percentage of Incident Ions
^{1}H	9.3145E+18	8.90%	0.0000E+00	0.00%
^{2}H	8.0677E+19	11.58%	0.0000E+00	0.00%
^{3}H	3.9956E+19	5.68%	0.0000E+00	0.00%
^{3}He	6.1327E+17	2.53%	0.0000E+00	0.00%
^{4}He	7.6584E+18	9.86%	0.0000E+00	0.00%
C	5.2632E+19	51.43%	0.0000E+00	0.00%



- Even at 8 mtorr, a significant number of ions are thermalized in the Xe buffer gas.
- At 8 µtorr, no ions are thermalized in the gas, which should be the case for a chamber pressure equivalent to a vacuum.
- The amount of energy deposited in the wall is greatly influenced by the amount of gas in the chamber.
- 8 mtorr of xenon in the chamber reduces the amount of ion energy depositing in the tungsten armor by (~25%) vs. vacuum conditions.

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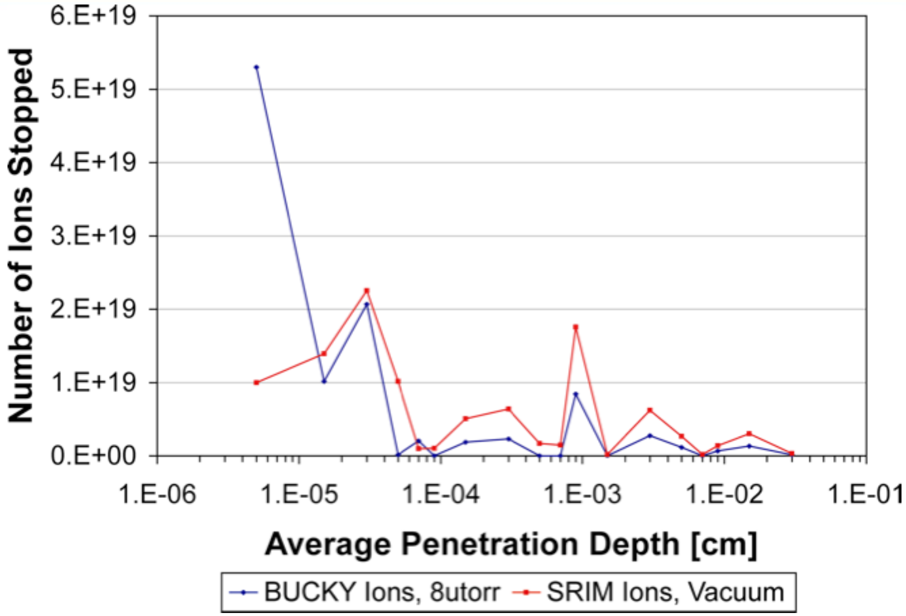
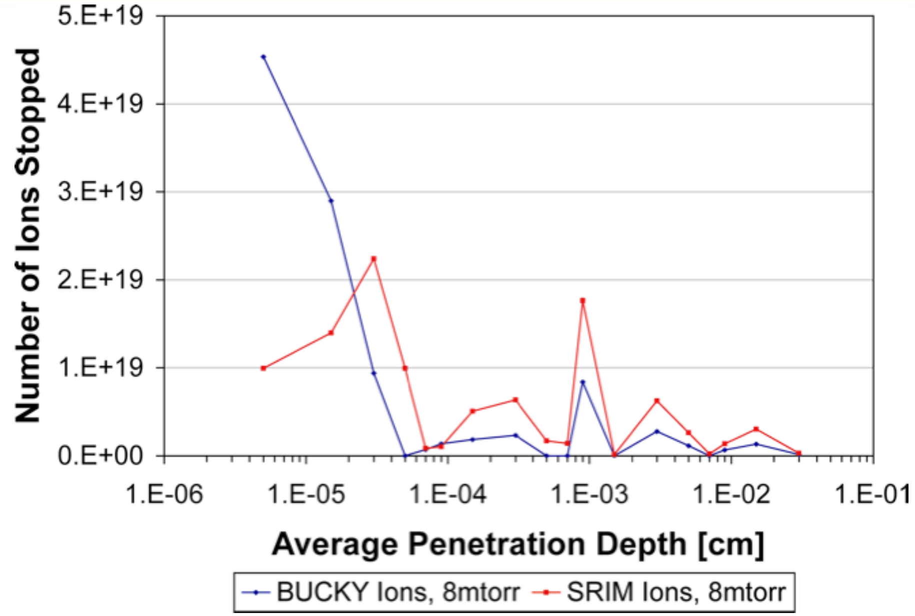
[1]H (Proton) Ion Deposition in the tungsten armor for 8 μtorr and 8 mtorr xenon gas pressures





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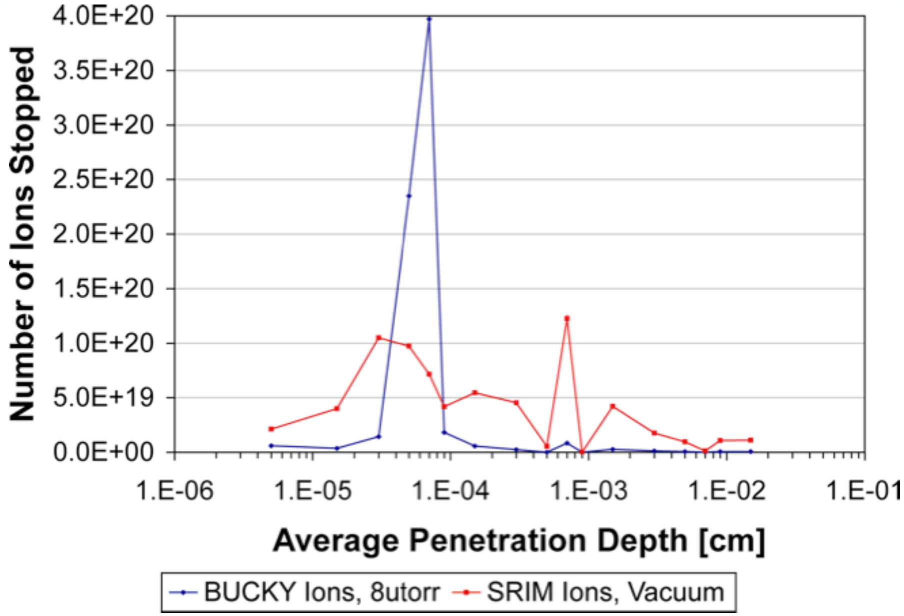
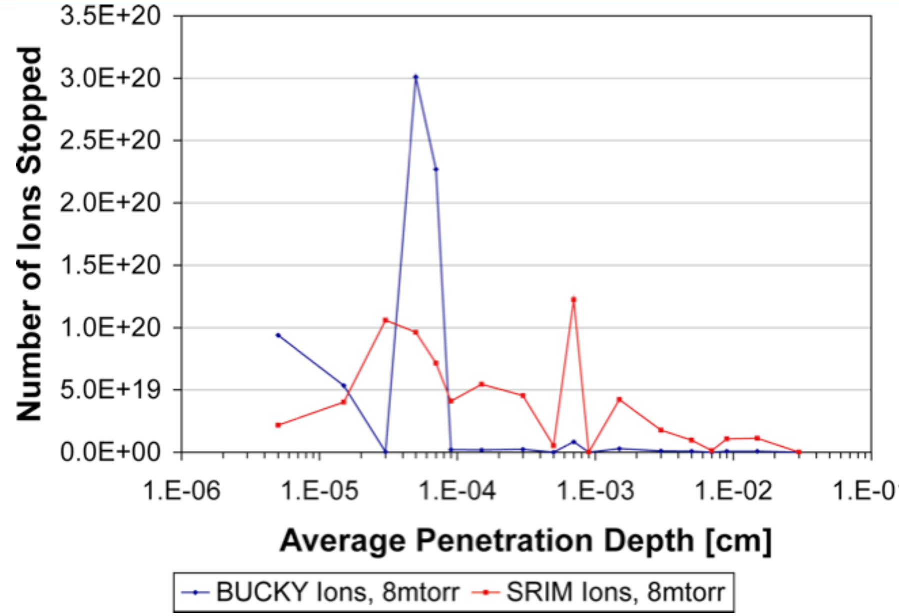
^{2}H (Deuteron) Ion Deposition in the tungsten armor for 8 μtorr and 8 mtorr xenon gas pressures





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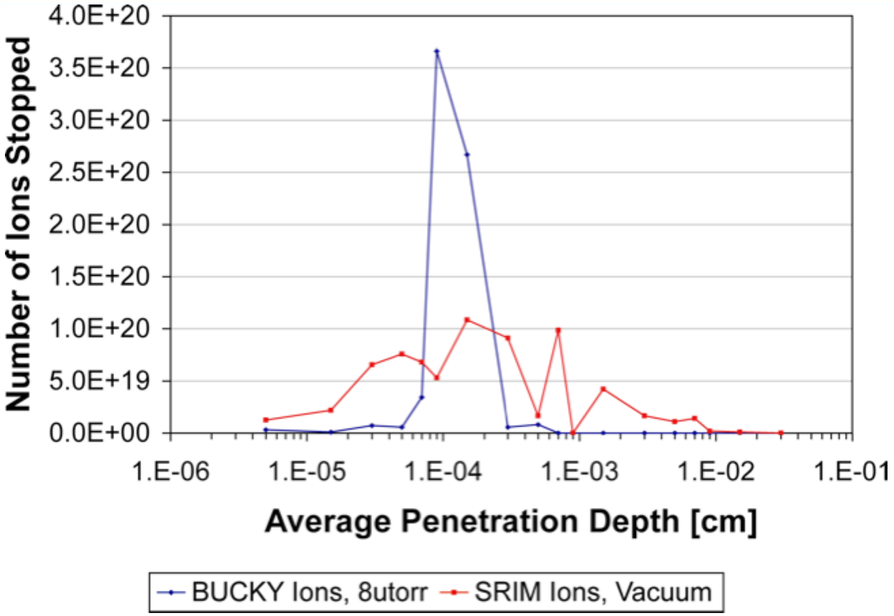
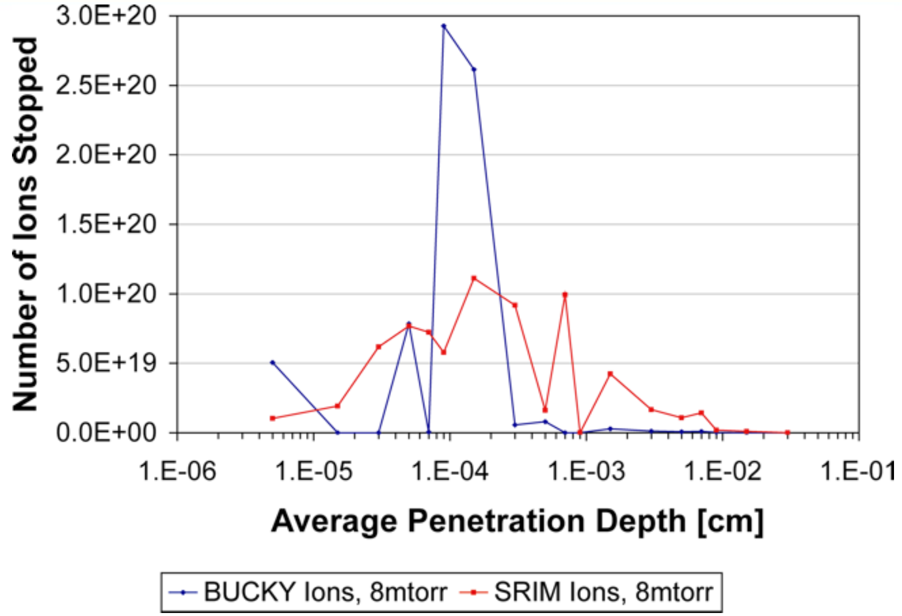
^3H (Triton) Ion Deposition in the tungsten armor for 8 µtorr and 8 mtorr xenon gas pressures





- SRIM results have broader deposition range due to straggling that is absent in BUCKY ion slowing down model.
- Agreement is otherwise good for the purpose of scoping calculations.
- A vacuum target chamber results in 70% of the tritium embedding in the tungsten armor to depths up to 100 µm on each shot. → $n_T = 4 \times 10^{23}$ cm^{-3} per FPY = 10x solid!
- How much of the tritium diffuses out and over what time scale?
- What other effects are created by ions embedding in the armor?

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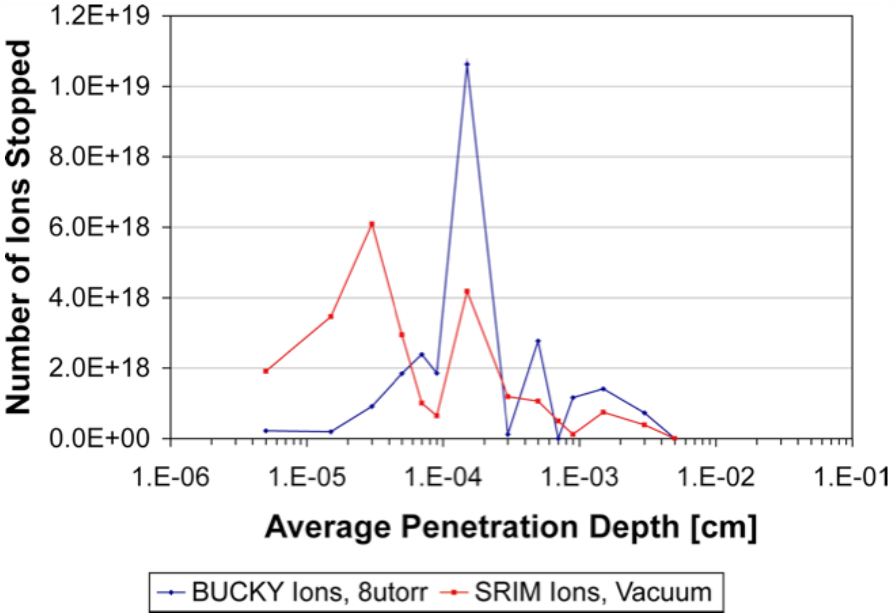
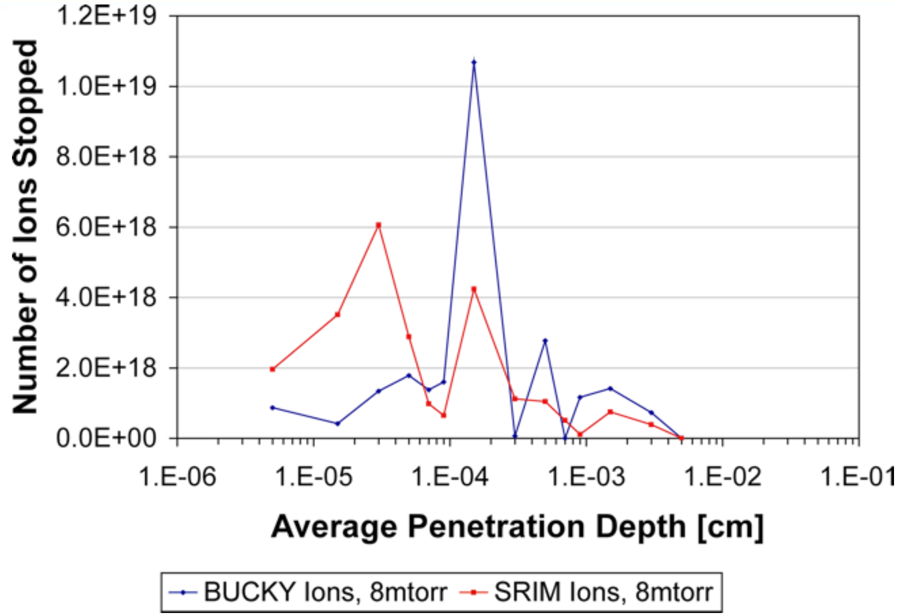
^3He Ion Deposition in the tungsten armor for 8 μtorr and 8 mtorr xenon gas pressures





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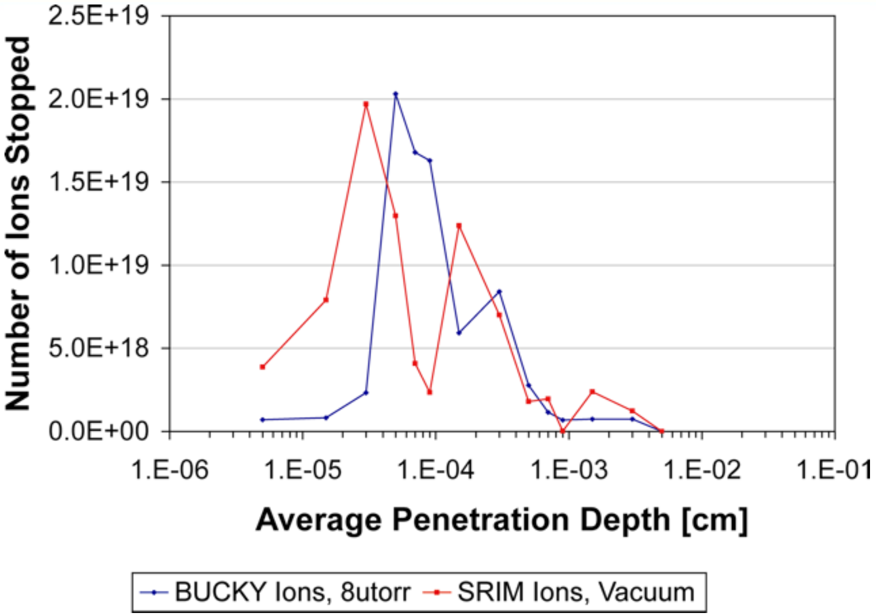
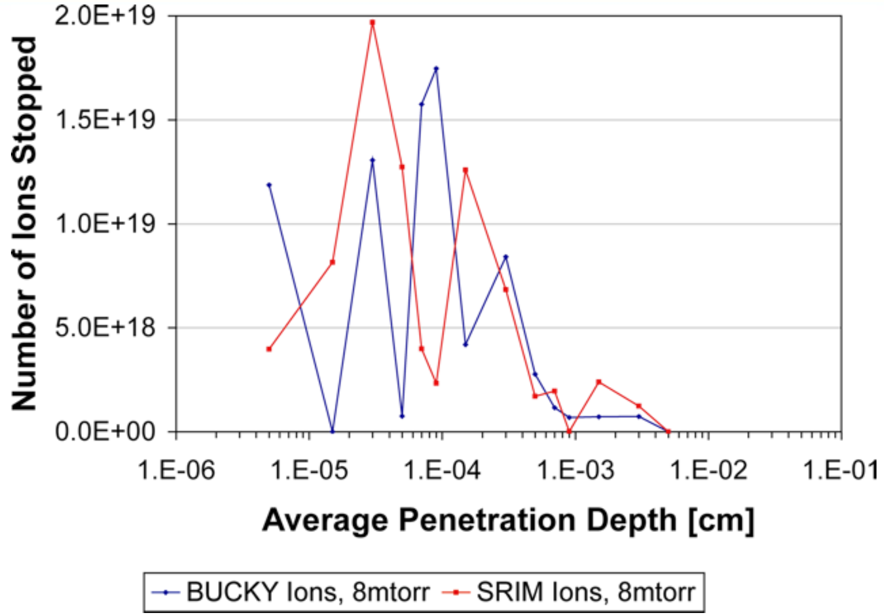
^{4}He (Alpha) Ion Deposition in the tungsten armor for 8 μtorr and 8 mtorr xenon gas pressures





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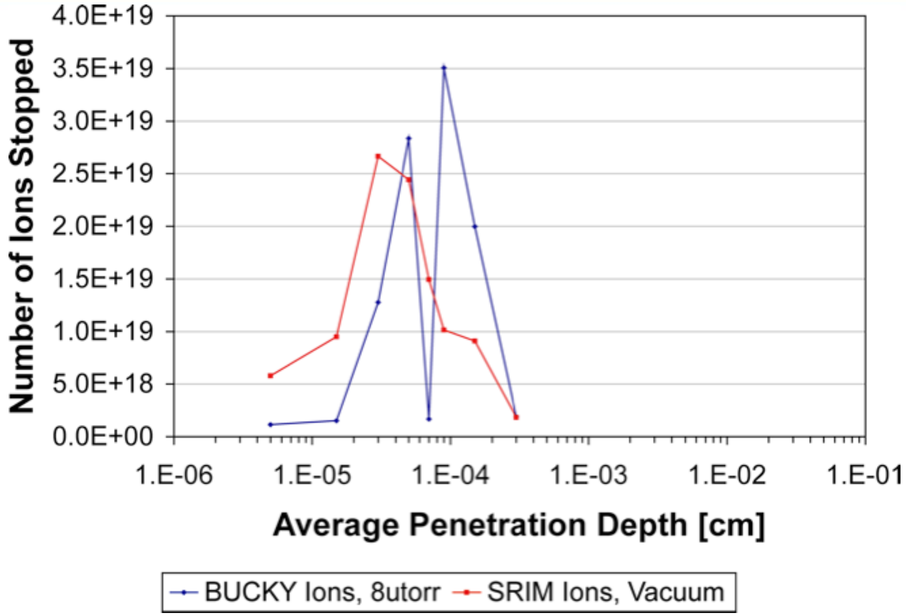
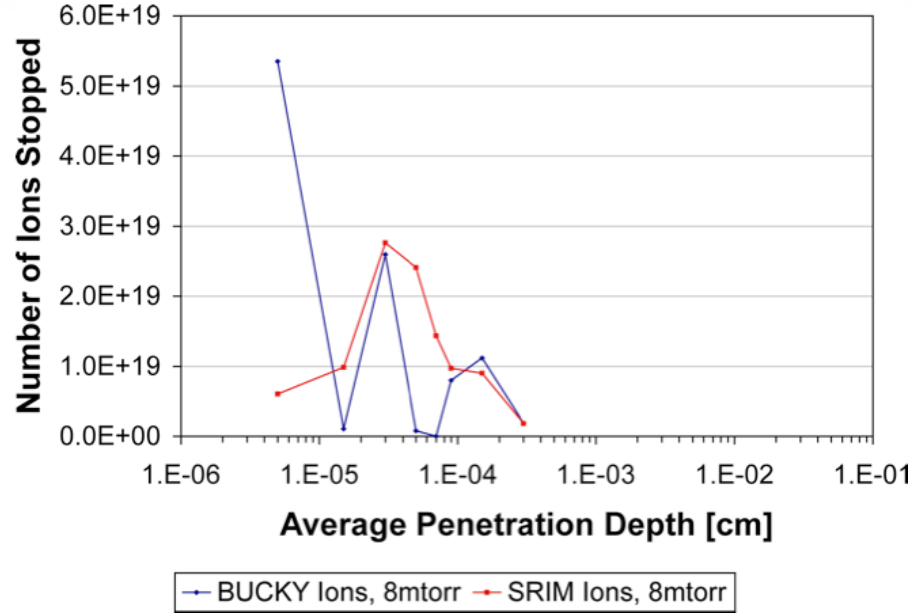
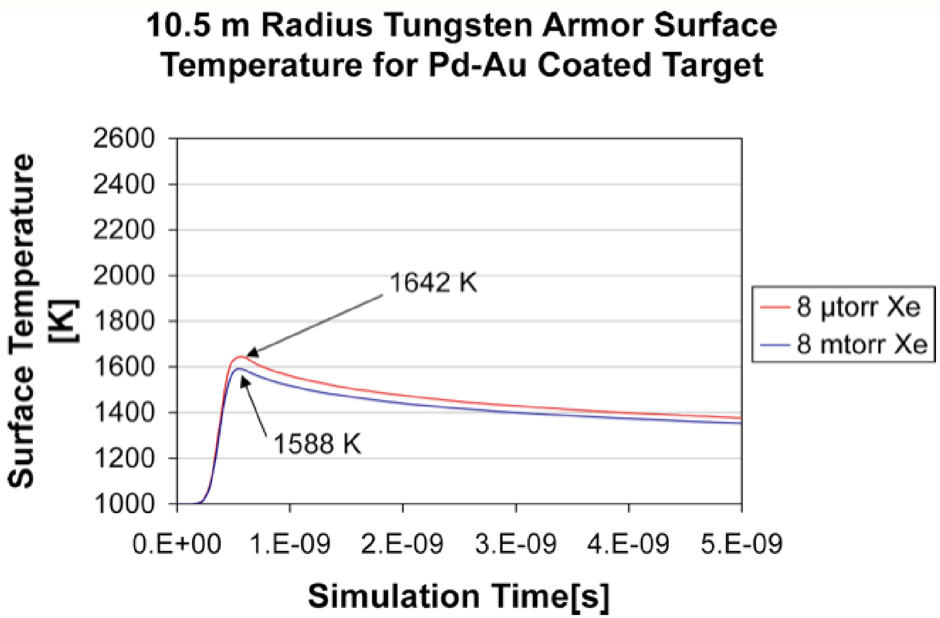
^{12}C (Carbon) Ion Deposition in the tungsten armor for 8 μtorr and 8 mtorr xenon gas pressures

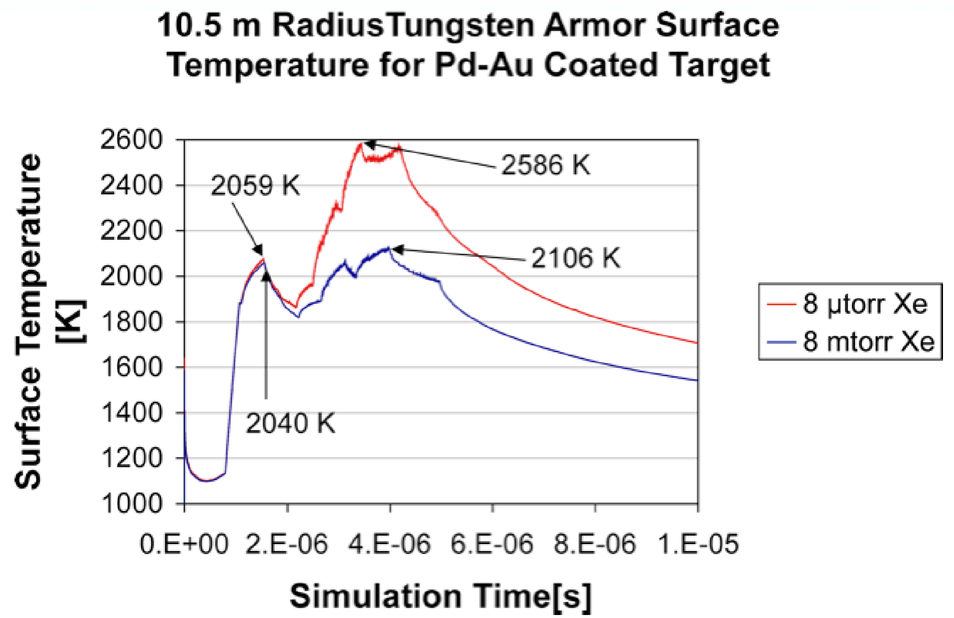


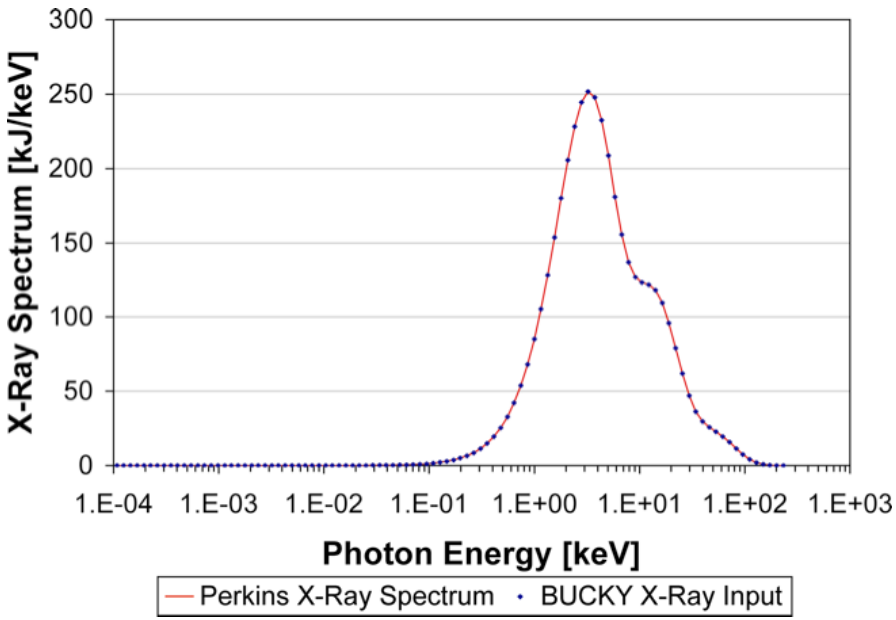


- Tungsten carbide formation? Modification of properties?

Preliminary temperature results from the palladium-gold coated target simulation have been computed







- Max surface temperature higher than in foam target; 2586 K vs. 2427 K.

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Kinetic Modifications to the Threat Spectra on IFE Reactor First Walls

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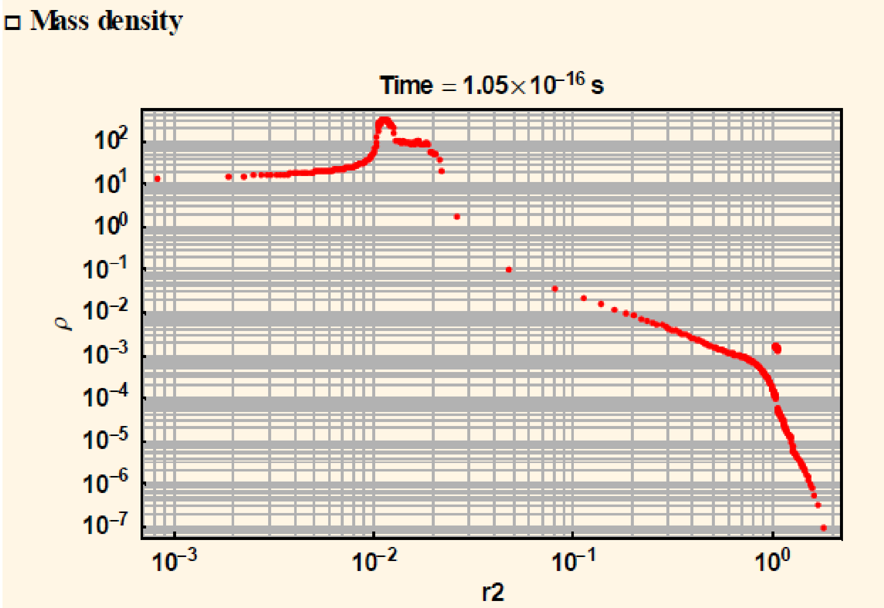
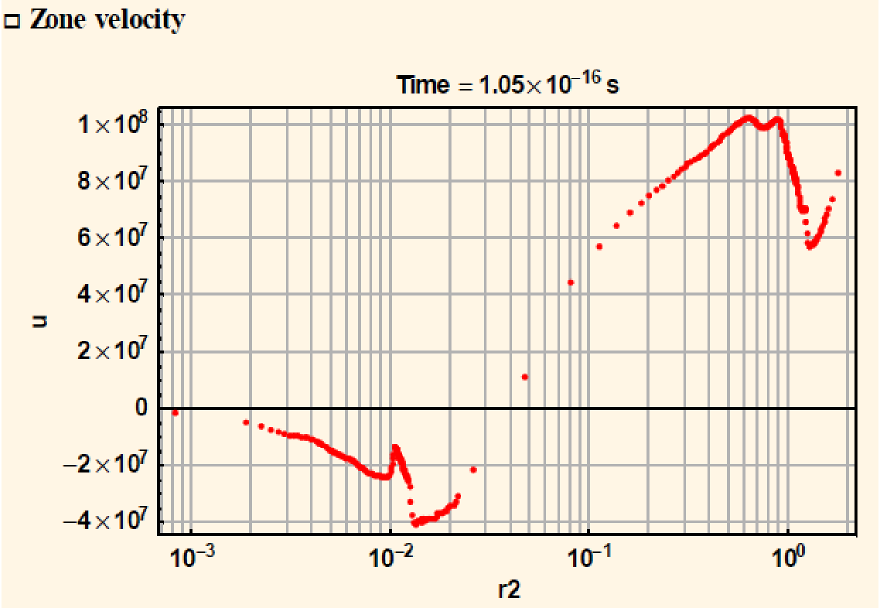
J.F. Santarius and G.A. Moses

We use a simple lagrangian hydro model of the HAPL plasma expansion to test long mean free path models





- Model (pure hydrodynamics) equations:
  1) $\partial u/\partial t + \partial p/\partial m = 0$
  2) $\partial e/\partial t + p(\partial V/\partial t) = 0$

- Solved by finite differences

- Initial conditions shown above

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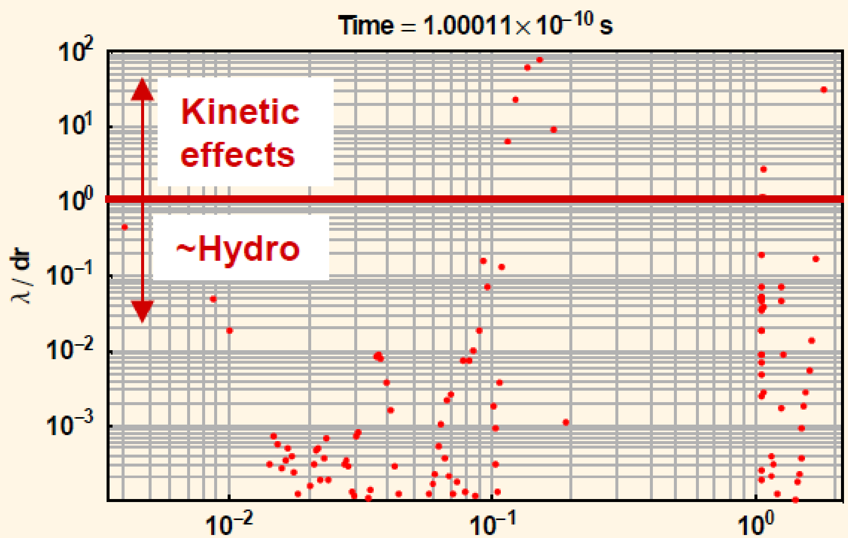
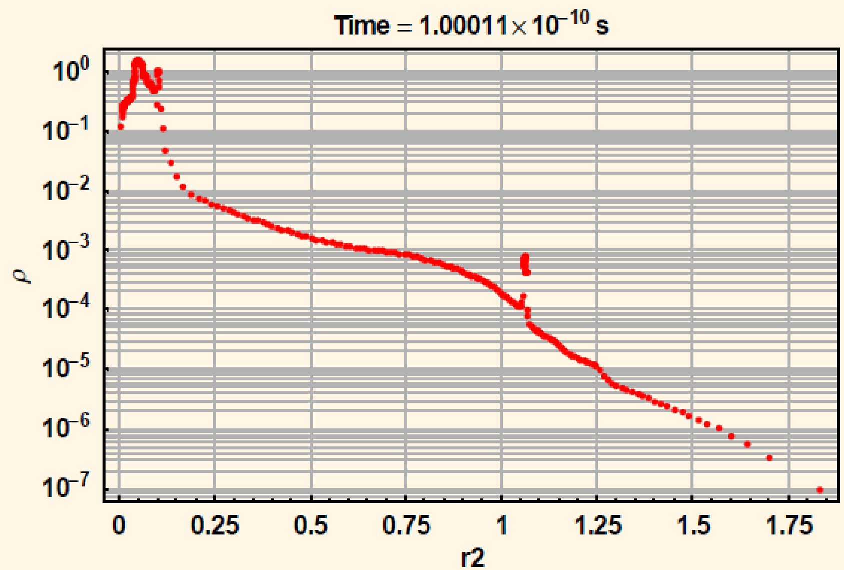
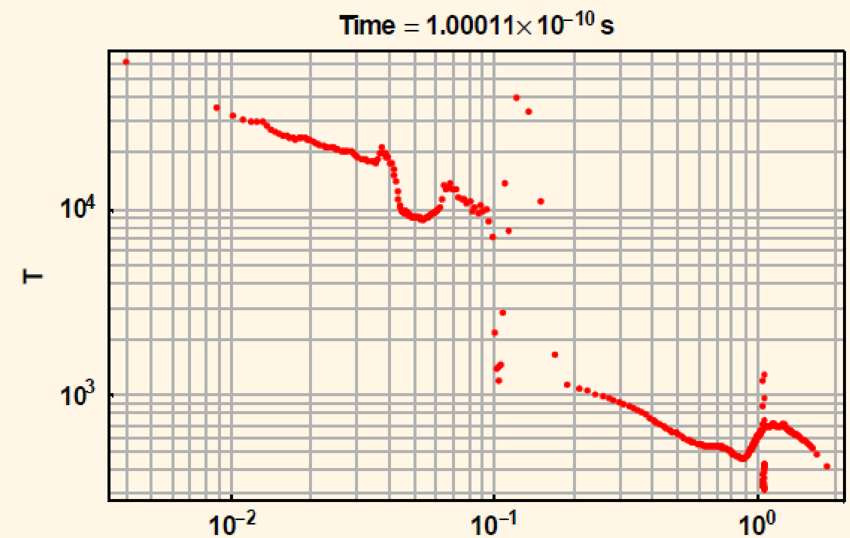
Simple lagrangian model indicates that kinetic effects are important for HAPL plasmas

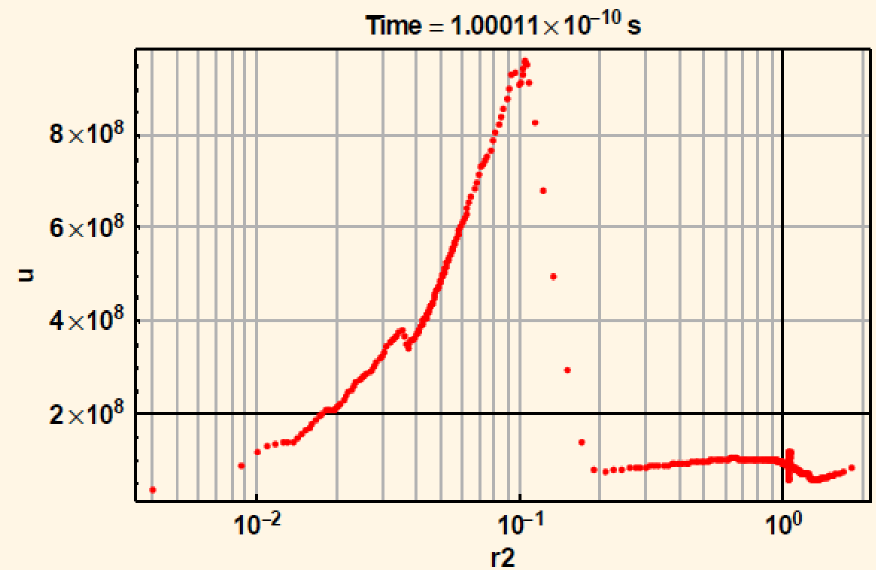
- Mean free path / zone thickness





- Temperature





Zone overlap will be modeled by conserving zone momenta when adjusting radii

Equations

In[132]:=

eqp1 = $m_1 u_1 == m_1 v_1 + \delta p$;

In[133]:=

eqp2 = $m_2 u_2 == m_2 v_2 - \delta p$;

In[136]:=

eqs1 = $z_1 == r_2 + v_1 \delta t$;

eqs2 = $z_2 == r_1 + v_2 \delta t$;

eqs3 = $z_3 == r_3 + v_1 \delta t$;

eqs4 = $z_3 == r_2 + v_2 \delta t$;

Zone overlap resolution

In[146]:=

$$\text{eqp} = \frac{(s_2^3 - z_2^3)}{(z_4^3 - z_2^3)} m_1 v_1 == \frac{(z_3^3 - s_2^3)}{(z_3^3 - z_1^3)} m_2 v_2;$$

In[147]:=

sls2 = Solve[eqp, s_2];

In[152]:=

sls2[[1]]

Out[226]=

$$\frac{\left(m_1 v_1 z_2^3 (-z_1^3 + z_3^3) + m_2 v_2 z_3^3 (-z_2^3 + z_4^3)\right)^{1/3}}{\left(m_1 v_1 (-z_1^3 + z_3^3) + m_2 v_2 (-z_2^3 + z_4^3)\right)^{1/3}}$$

For a momentum change δp, the middle radius, s1, is chosen by equating the momentum shifted when resolving the overlap.